DAMAGE TO STATE HIGHWAY 73 FROM THE 29 MAY 1995, ARTHUR'S PASS EARTHQUAKE

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ABSTRACT

On 29 May 1995, a magnitude M 5.5 earthquake centred near Arthur's Pass caused considerable damage to State Highway 73 in Arthur's Pass National Park, almost a year after the highway was closed by a magnitude M 6.5 earthquake. Although earthquake magnitudes and epicentral locations for the two events accounted for some differences in extent and severity of slope failure and highway damage, the lower magnitude 1995 earthquake initiated significant rockfall above the Zig Zag, unaffected by the 1994 earthquake. The greater ground damage than anticipated at the Zig Zag and in Otira Gorge could be due more to direction of seismic wave propagation relative to Otira Valley, and predisposition of slope materials to failure, than to earthquake magnitude.

INTRODUCTION

The 29 May, 1995 Arthur's Pass earthquake occurred prior to completion of major slope stabilisation work being carried out above the highway in Otira Gorge following the 18 June, 1994 Arthur's Pass (Avoca River) earthquake. Damage from both earthquakes resulted in considerable disruption to highway traffic, and increased slope stability hazards to highway users. Other consequences include the cost of repairs to reopen the highway, and implementation of slope stabilisation measures to mitigate hazards. General deterioration of stability of slope materials along the highway as a result of the earthquakes is being assessed in terms of possible effects on the Otira Viaduct, currently in the design phase, and planned highway upgrading of the partially single lane, Otira Gorge section.

This paper describes highway damage and slope instability caused by the 29 May 1995 Arthur's Pass earthquake and compares the effects with those caused by the 18 June 1994 Arthur's Pass (Avoca River) earthquake [Berrill et al, 1995; Patterson and Bourne-Webb, 1994; Pattle and Wood, 1995; Van Dissen and Berryman, 1995]. Information for this paper was obtained during a survey of highway damage carried out for Works Consultancy Services on 30 May 1995, and ongoing engineering geological investigations associated with highway repair and slope stabilisation . One of the authors (B. R. Paterson) is also involved in design investigations for the Otira Viaduct being carried out by Beca Carter Hollings and Ferner on behalf of Transit New Zealand.

EARTHQUAKE LOCATION

The epicentre of the magnitude M 5.5 earthquake which occurred at 10.06pm on 29 May 1995, is located at latitude 40.90 south, longitude 171.40 east, approximately 14 km west of Arthur's Pass (Figure 1). No damage was reported from the main shock which was reported felt in Arthur's Pass township, Christchurch, Greymouth and Nelson (Institute of Geological and Nuclear Sciences). Numerous aftershocks were reported by Arthur's Pass residents, but these were not recorded by seismic instruments. An accelerograph installed in Arthur's Pass township was triggered by the earthquake and recorded peak accelerations of 0.37g vertically and 0.28g horizontally (see Appendix).

The epicentre of the 1995 earthquake is located approximately 16 km northwest of the 18 June 1994 main shock, at the northern end, and on the alignment, of a well defined zone of seismic activity associated with the 1994 earthquake [Arnadottir et al, in press]. This places the 1995 earthquake closest to the Zig Zag and Otira Gorge where the highway suffered most damage. The location of the 1995 earthquake in relation to both the northwest trending, 1994 seismic zone (Figure 1), and the southern branch of the Hope Fault (Kelly Fault) is geologically significant. This aspect may be elucidated during further investigation. No reports of surface fault rupture associated with the 1995 earthquake have been received.

EARTHQUAKE DAMAGE

General Description

Investigation of earthquake damage on 30 May 1995 consisted of a helicopter survey along SH73, through Arthur's Pass National Park, between Paddys Bend and Otira township (Figure 1), followed by detailed assessment of unstable sites along the highway. Aerial and ground surveys of ground damage were confined to the highway corridor along the Bealey and Otira Valleys and did not extend into the epicentral area west of Arthur's Pass.

South of Arthur's Pass, the earthquake caused only minor rockfall from highway batters or adjacent slopes, and localised reactivation of 1994 slump cracking along sections of highway

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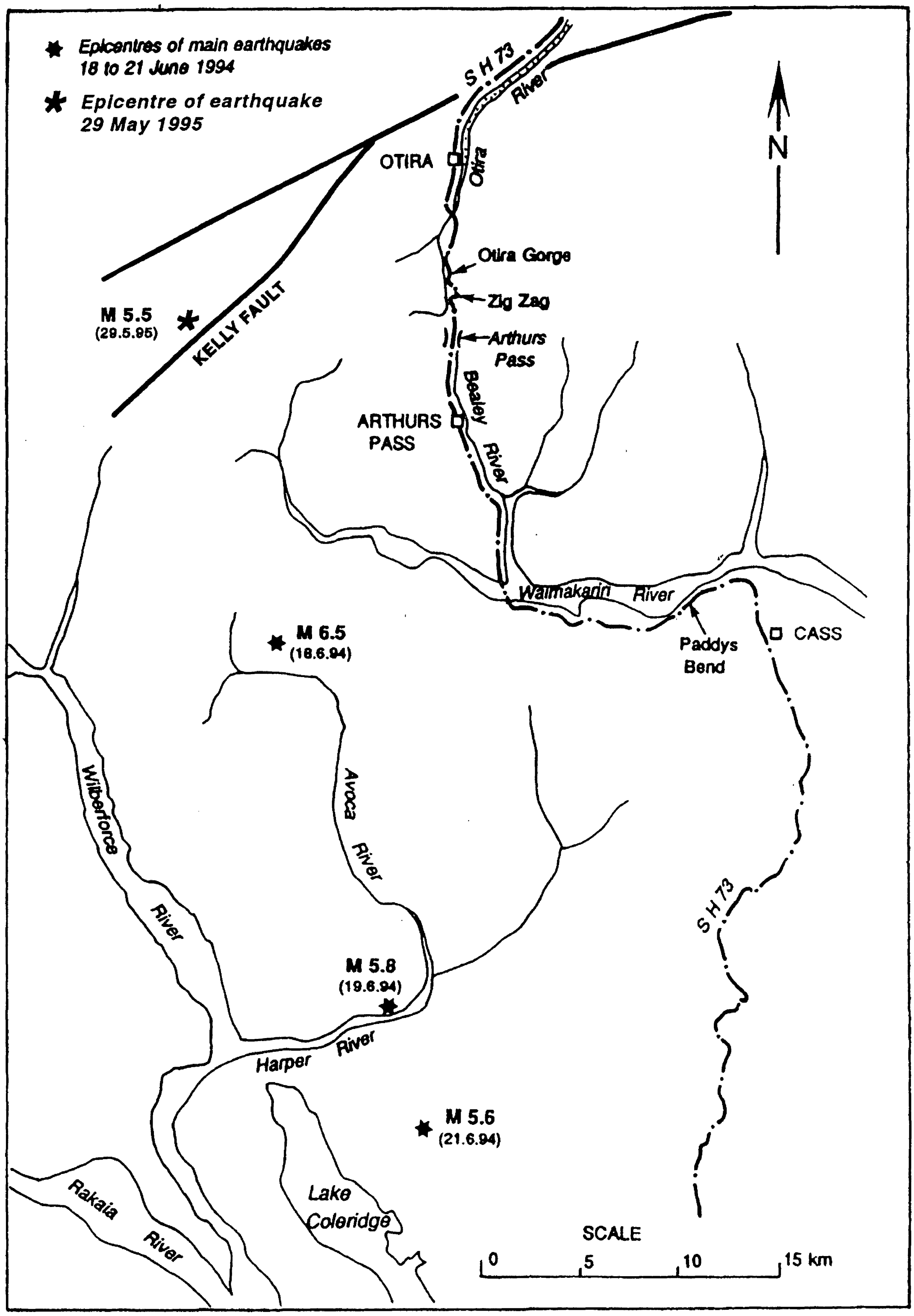

FIGURE 1 Map showing localities on State Highway 73 in relation to earthquake epicentres.

embankment fill, neither of which prevented restricted traffic movement. Aerial inspection at Paddys Bend was carried out to check on stability of rock bluffs above the highway loosened by the 1994 earthquake - no significant deterioration was detected. At the Zig Zag, 2 km north of Arthur's Pass, where the highway climbs over a large rock avalanche deposit, numerous large (1-2 m) blocks of rock were scattered along the highway (Figure 2), several of which caused impact damage to the pavement. Rockfall onto the highway, and slumping along the edge of over-steepened slopes beneath critical sections of the highway near the top of the Zig Zag, were more pronounced than during the 1994 earthquake.

As in the 1994 earthquake, the largest slope failures directly affecting the highway occurred in Otira Gorge where rockfall, several large (>1000 m^3) debris slides and a large rockslide deposited a large amount of material onto the highway. Several were reactivated 1994 slope failures, and the remainder occurred adjacent to slope failures initiated by the 1994 earthquake. In general, the most serious ground damage occurred at steep rock spurs and on slopes of colluvium and dilated bedrock over steepened by river erosion and highway construction.

Removal of debris from the highway and stabilisation of adjacent slopes in Otira Gorge closed the highway for five days and caused delays for several weeks when wet weather initiated further slope failures. Further slope failures during the following winter months indicate the long-term detrimental effect of the recent earthquakes on the stability of slope materials.

Earthquake Damage at the Zig Zag

1. Rockfall

Blocks of greywacke sandstone fell onto the highway at the top of the Zig Zag and at several hairpin bends where the highway descends into Otira Gorge. These sections of the highway sidle across the toe of extensive scree deposits which extend almost 400 m upslope to the base of rock bluffs, the headscarp of the Otira rock avalanche [Patterson et al, 1992]. Most blocks rolled onto the highway from batters and adjacent scree deposits, causing no significant damage. Several blocks 1.5 m diameter, created impact craters on the highway indicating that they had originated from a considerable height above the highway (Figures 3 & 4). During the helicopter survey, the tracks of individual blocks were traced through bush above the highway onto the upper scree slopes where tongues of rock debris, deposited by rockfall during the earthquake, were identified by their "fresh" appearance (Figure 5). Sources of rockfall on the headscarp above the scree deposits were also identified by scars (Figure 6). The main rockfall source occurs at the head of the northern most, scree fan (Figure 5), with several minor sources being located along the headscarp to the south.

Judging by the continuous tracks through the bush, blocks rolled down the 35-38 degree slopes above the highway. All blocks that damaged the highway came to rest on, or adjacent to the highway. One block at the northern end of the Zig Zag formed impact craters at two levels of the highway where it crossed a hairpin bend. This indicates that rockfall blocks released from the headscarp above the scree deposits did not reach a high velocity, and therefore are unlikely to have crossed the highway without trace. This conclusion is consistent with a computer simulated analysis of rockfall at this site commissioned by Beca Carter Hollings and Ferner during design investigations for the Otira viaduct.

Rockfall also originated from steep slopes of rock avalanche debris below the highway, judging by fresh scars observed where blocks were released from over steepened slopes immediately below the highway (Figure 7), and by accumulation of blocks on the drilling access track at the foot of the slope (Figure 8). Blocks up to 4 m diameter fell onto the track, and

FIGURE 2 Blocks of rock on the highway at the top of the Zig Zag.

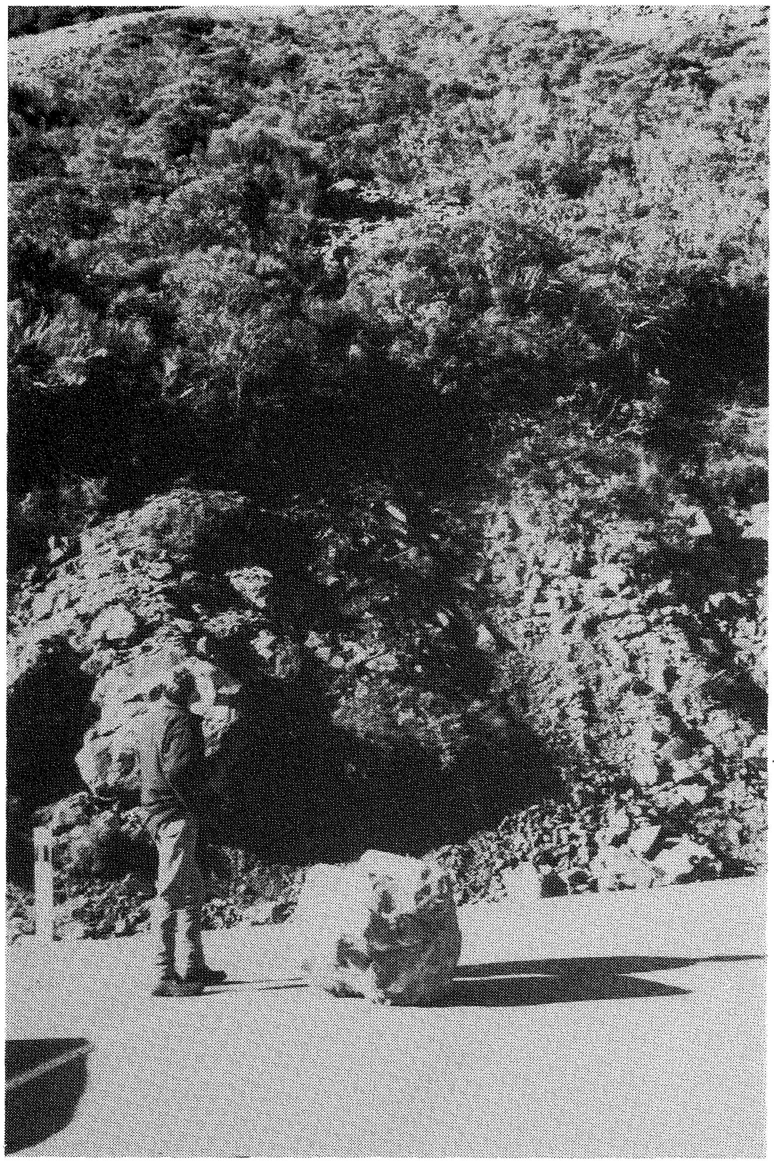

FIGURE 3 A block of rock on the highway at the Zig Zag.

FIGURE 4 Impact crater on the highway near the top of the Zig Zag.

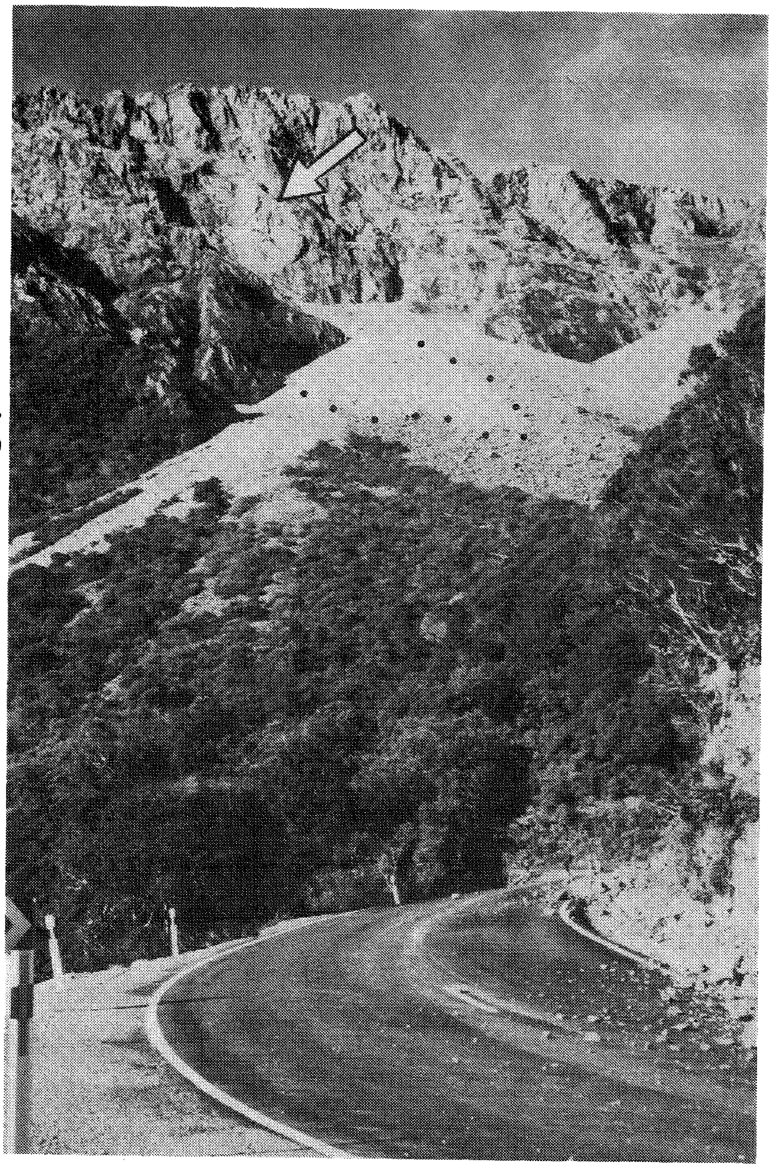

FIGURE 5 Fresh rockfall debris on the northern scree deposit (highlighted) and main rockfall source (arrowed) above the Zig Zag.

FIGURE 6 Detailed view of highly fractured greywacke at the rockfall source above the Zig Zag. Note undisturbed rock in upper photograph.

FIGURE 7 Sources of rockfall (arrowed) from rock avalanche debris below the highway at a Zig Zag hairpin bend. Note highway barrier top left.

FIGURE 8 Large rockfall blocks (arrowed) on the access track below the Zig Zag. Otira River flows left to right.

impact craters on the track indicated that several blocks continued into the river below. This demonstrates the need to mitigate the hazard of further rockfall during future investigation and construction work for the viaduct, and the necessity for protection of the viaduct during its operational life, aspects addressed in the design of the viaduct.

2. Highway Collapse

Slumping occurred along the edge of the highway at several locations, including at the top of the Zig Zag (Figure 9), and at the second hairpin to the north. Linear, parallel slump cracking occurred along the edge of the pavement several metres back from the edge of the highway bench. The ground fracturing appeared to be relatively superficial, although there was concern that surface fracturing along the highway, and rockfall from the slopes beneath the highway, may indicate initiation of deep seated circular failure. At both locations, slopes beneath the highway have been over steepened by gradual degradation of in situ, rock avalanche debris, with the result that if circular failure occurred, part, or the entire width of the highway bench could collapse, closing the route for a considerable period.

On the basis of existing data it was concluded that the ground disturbance from earthquake shaking was relatively superficial. However, because of the lack of definitive data and as a precautionary measure, the width of the carriageway was reduced, an inspection programme to detect further ground fracturing was implemented, and investigation of temporary by-passes at both sites was initiated.

Earthquake Damage in Otira Gorge

The highway was blocked by several slope failures in Otira Gorge the two largest of which occurred at the southern approach to Yorkys Bridge, and a short distance north of Wesley Creek. Rockfall occurred along the partially single lane section north of Candys Creek and at most sites through the gorge where the highway passes beneath over steepened rock slopes. Minor rockfall occurred at the site near Reids Falls where a large rockslide covered the highway and partially dammed Otira River during the 1994 earthquake [Patterson and Bourne-Webb, 1994]. Removal of unstable rock from overhanging spurs, such as Starvation Point, delayed reopening of the highway beyond the time taken to clear debris from the large slope failures. Abseilers used explosives and hand scaling methods to remove dilated rock shattered by earthquake shaking. These methods were more appropriate than helicopter sluicing, used to great effect at the site of the large rockslide after the 1994 earthquake.

At Yorkys Bridge, several large blocks of greywacke sandstone which formed a prominent spur of bedrock overhanging the southern end of the old wooden truss bridge, were displaced by the earthquake, ending up on the highway, blocking the southern approach to the existing bridge (Figure 10). A relatively small block was dislodged from the end of the spur during the 1994 earthquake, and at that time it was recognised that further material could be mobilised by strong earthquake shaking. Failure of the spur probably resulted from the combined effects of an unfavourably oriented basal joint, isolation of the rock spur from the adjacent rock mass, and rock mass disturbance created by the 1994 earthquake.

Near Wesley Creek, a 2000-3000 m^3 slope failure of highly weathered, dilated greywacke was initiated by the 1995 earthquake at a location adjacent to two previous slope failures caused by the 1994 earthquake (Figure 11).

FIGURE 9 Tension cracks (bottom right) along the edge of oversteepened slope at the top of the Zig Zag.

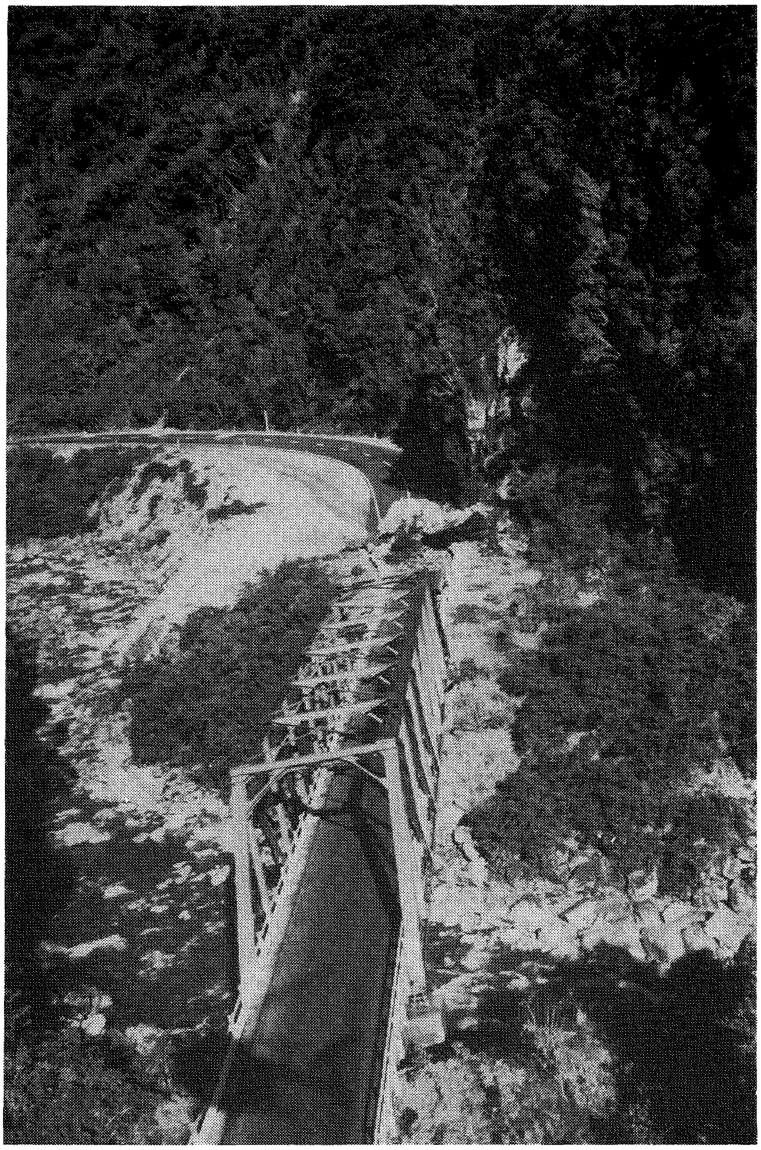

FIGURE 10 Rockslide at the southern end of Yorkys Bridge, Otira Gorge.

FIGURE 11 Rockslide near Wesley Creek, Otira Gorge.

DISCUSSION

By comparison with widespread effects caused by the 1994 earthquake, the localised area of slope instability along the SH73 corridor in Arthur's Pass National Park was indicative of the lower magnitude, and closer proximity of the 1995 earthquake. In contrast with the 1994 earthquake, the pattern of ground damage in the highway corridor is related to distance from the epicentre - the extent of ground damage outside the corridor is unknown.

The greater ground damage than anticipated at the Zig Zag and in Otira Gorge could be due more to direction of seismic wave propagation relative to Otira Valley, and predisposition of slope materials to failure, than to earthquake magnitude. Occurrence of two events of high intensity shaking within a short period of time, following a comparatively long period of low seismic activity, probably caused cumulative deterioration of the rock mass. Rockfall from above the Zig Zag was initiated in 1995 by seismic waves travelling across Otira Valley, whereas seismic waves generated by the 1994 earthquake, travelling subparallel to Otira Valley, did not produce primary rockfall at this site. In both events, site specific factors played an important role in focusing the damaging effects of earthquake shaking.

ACKNOWLEDGEMENTS

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REFERENCES

1. J B Berrill, K J McManus and G H Clarke, 1995, A note on the Arthur's Pass earthquake, 18 June 1994. *Bull. of N.Z. National Society for Earthquake Engineering,* 28(4):

2. B R Paterson and P J Bourne-Webb, 1994, Reconnaissance report on highway damage from the 18 June 1994 Arthur's Pass earthquake. *Bull. of N.Z. National Society for Earthquake Engineering,* 27(3):222-226.

3. A Pattle and J H Wood, 1995, Ground shaking intensity and damage at Lake Coleridge Power Station in the 18 June 1994 Avoca River Earthquake. *Bull. of N.Z. National Society for Earthquake Engineering,* 27(3):227-230.

4. R J Van Dissen and K R Berryman, 1995, The Arthur's Pass (Avoca) earthquake of 18 June, 1994: an overdue note regarding landslide damage and the search for surface rupture. *Geological Society of N.Z. Newsletter,* 107:28-33.

5. T Arnadottir, J Bevan and C Pearson. In press. Deformation associated with the 18 June, 1994, Arthur's Pass earthquake, New Zealand. *N.Z. J. of Geology and Geophysics.*

6. B R Paterson, M J McSaveney and M E Reyners, 1992, The hazard of rockfall and rock avalanches at the Zig Zag, SH73 Arthur's Pass. *DSIR Geology & Geophysics contract report 1992/14.*

APPENDIX
May 29, 1995 Accelerogram

The accelerogram shown below (Figures A1 and A2) was recorded in the park headquarters building at Arthur's Pass Township on an SMA-1 accelerograph belonging to the University of Canterbury. The record is notable for its high peak accelerations for a modest M5.5 event. The peaks were 37% in the vertical direction and 28% in the east-west direction, across the valley at the site.

Acknowledgement

The authors wish to acknowledge the contribution of Mr G H Clarke in maintaining the instrument and in processing the record. Thanks are also due to the Park Headquarters personnel for their day to day care of the accelerograph.

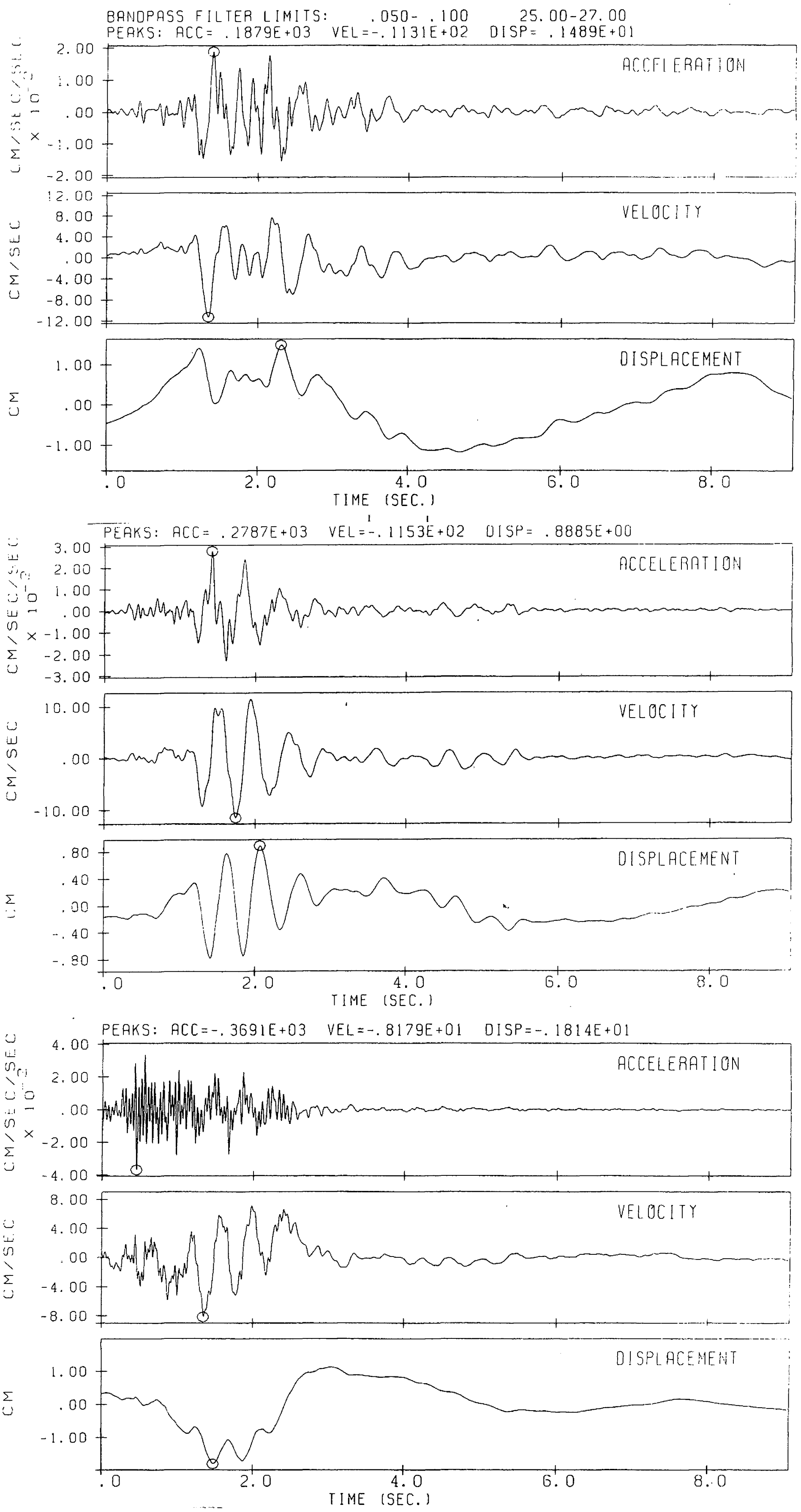

***FIGURE A1** Corrected acceleration, velocity and displacement traces in the North-South direction (top), East-West (middle) and vertical (bottom).*

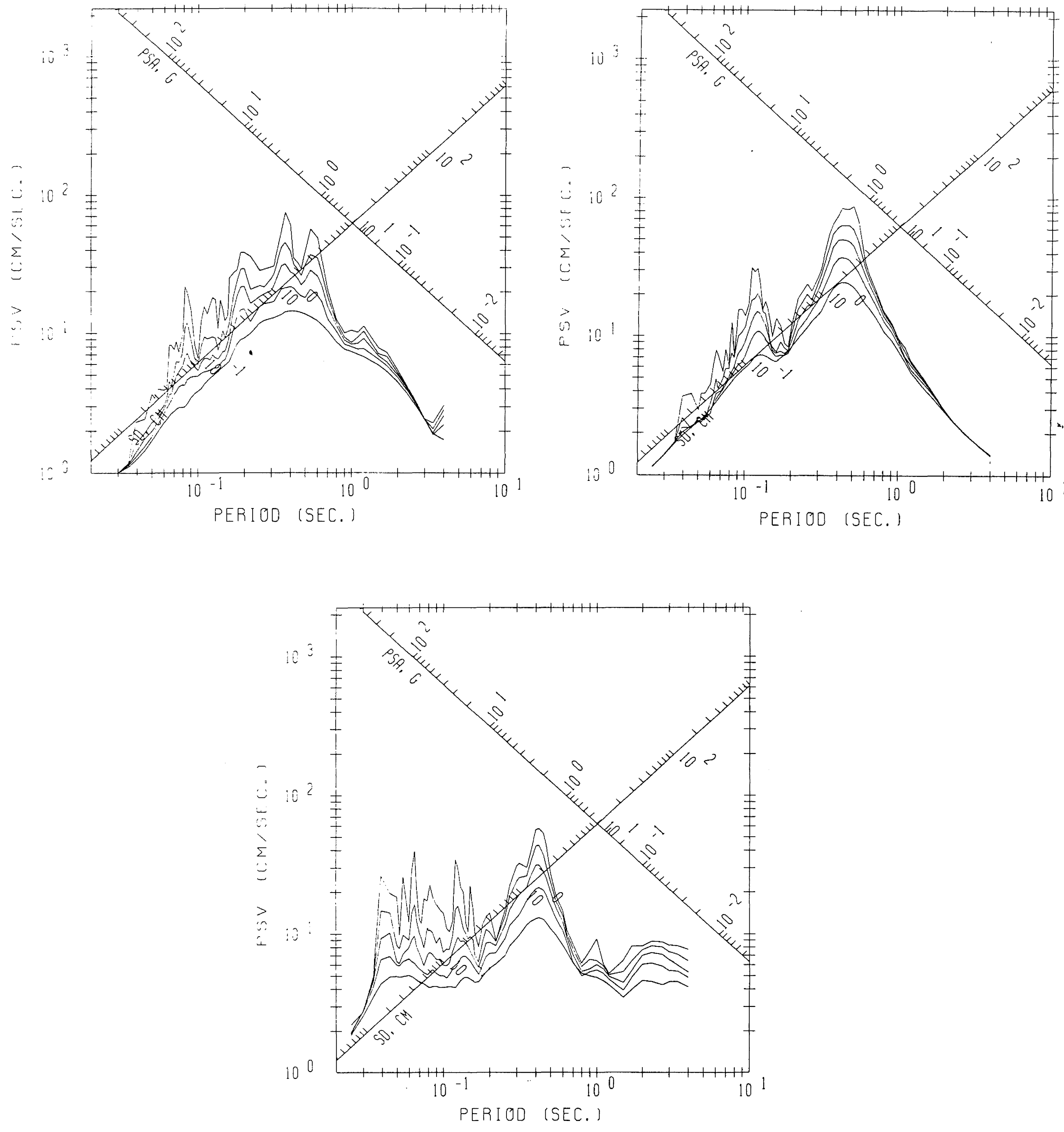

FIGURE A2 Pseudo velocity response spectra of the 29 May, 1995 recording measured North-South (top left), East-West (top right) and vertical (bottom). Damping values are 0, 2, 5, 10 and 20 percent.